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PHYSICAL PARAMETERS IN RELATION TO PHYSIOLOGICAL CHANGES OF AVOCADO DURING RIPENING (20ºC) AND COLD STORAGE (6ºC) IN DIFFERENT CONDITIONS.

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Abstract

The application of the response of fruits to low energy mechanical impacts is described, for evaluation of post-harvest ripening of avocadoes of the cultivar "Hass". An impactor of 50g of weight, provided with an accelerometer, and free-falling from a height of 4 cm, is used; it is interfaced to a computer and uses a special software for retrieving and analyzing the deceleration data. Impact response parameters of individual fruits were compared to firmness of the pulp, measured by the most used method of double-plate puncture, as well as to other physical and physiological parameters: color, skin puncture ethylene production rate and others. Two groups of fruits were carefully selected, stored at 6ºC (60 days) and ripened at 20ºC (11 days), and tested during the storage period. It is shown that, as in other types of fruits, impact response can be a good predictor of firmness in avocadoes, obtaining the same accuracy as with destructive firmness measurements. Mathematical and multiple regression models are calculated and compared to measured data, with which a prediction of storage period can be made for these fruits.

1. Introduction

Avocado, like other climacteric fruits, continues its evolution after being harvested. This type of fruits, during their way to total ripeness soften. This is only one aspect of all the complex processes which fruits undertake during postharvest ripening, and which will determine their quality to the consumer. Therefore, firmness or hardness of the fruit flesh can be (and is generally) used as an indicator to classify fruits into different ripeness classes.

Subjective evaluation of flesh firmness is sometimes made non-destructively by finger pressure. Destructive puncture measurements have been successfuly solved by the application of a "double plate" device (De la Plaza et al., 1975) obtaining better results than Magness-Taylor and similar devices.

Non destructive firmness measurements or, in general, quality assessment, is being sought for years. Many different systems and techniques like density, mechanical and sonic vibrations, ultrasounds, nuclear magnetic resonance and others are investigated (Chen and Sun, 1991). Firmness is a mechanical property of the flesh of the fruits and recently, impact response has given excelent results in its measurement, along with other mechanical flesh properties. Many results of these techniques have been published, applied to different species and varieties of fruits. García et al.(1988) showed the strong relationship of some parameters of the impact response of fruits (apples and pears) with post-harvest ripeness. Ruiz-Altisent et al. (1989, 1990, 1990a, 1991), Jarén (1990), Jarén et al (1992) and Correa et al.(1991) have established the parameters which best estimate the ripening process, and have developed: a) an analytical system for the analysis the impact data, b) an impact device and c) a self-instructing software for the classification of fruits of any kind into maturity classes.

In this presentation, application of these techniques to avocado is described. Also, a discussion of a mathematical model that simulates post-harvest ripening process of climacteric fruits, as applied to avocado data.

2. Materials and methods

2.1. Fruits

Avocadoes of the cultivar "Hass" grown in Malaga (Spain) were collected and pre-selected: fruits which showed symptoms of softening, diseases or defects were eliminated; only fruits of homogeneous size and skin colour were selected for the tests.

2.2. Conditions of the tests

Fruits were put into plastic field-boxes, and after that, packed in low-density 0.025 mm polyethylene bags. Two large samples were made, for cold storage at 6ºC and for ripening at 20ºC. Fruits were tested on days 5,7,9 and 11 for the 20ºC sample, and on days 11,18,25,32,39,46,53 and 60 for the 6ºC sample. Each box containing 10 fruits made up a sampling unit (10 replications/test).

2.3. Testing techniques

2.3.1. Mechanical impacts

The described impact testing device was used. The free-falling impactor is a 19 cm diameter spherical tip, aprox.50 g of weight, and drop height of 4 cm was used. The accelerometer response of each impact is stored and analyzed by a PC through an appropriate software (García et al. 1988).

2.3.2. Firmness

Firmness was measured using a double-plate penetrometer on an Instron 1140 Universal Testing Machine. Each fruit was tested on three equally-spaced points on the equatorial area, after eliminating approximatelly 3 cm^2 of the peel, not affecting fruit flesh. Five fruits were randomly selected from each ten-fruit sampling unit.

2.3.3. Color

Color of flesh and skin, density, respiration and ethylene production (concentration of CO_2 and ethylene of the modified atmosphere), conductivity and skin puncture (by a 0.4 mm-diameter cylindical indentor) were also measured in part of the samples, and the results are described elsewhere (Correa, 1992)

2.3.4. Data Analysis

Principal components analysis was used to describe the relationships between measured and calculated parameters of ripeness, to select those to be used as ripeness indeces. Analysis of variance, comparison of means by Duncan's multiple range test ($p \leq 0.05$) and linear and non-linear regression analyses were applied to the data. Different mathematical models were thereafter tested and evaluated on the results.

3. Results

3.1. Impact parameters: correlations and multiple component analysis.

Taking firmness average value as the reference ripeness index for each sample, a number of impact response parameters were analyzed as estimates for fruit firmness. Table 1 shows the parameters, called variables, which best correlated with firmness in avocadoes. Included are two calculated coefficients: FT.FM (N^2/s) i.e. force/time slope times maximum impact force and FD.FM (N^2/mm), force/deformation slope times maximum impact force. Number of days of storage was also highly correlated to firmness.

Principal components analysis of the data showed that the variation of the 9 variables selected to describe the impact response/firmness/time of the ripening phenomenon can be reduced to two axes, which explain more than 90% of the total variance, for all samples (Table 2). Factor 1 shows correlations higher than 0.94 for all variables except for "days" of storage. This means that: 1) any one of the impact variables can be used to predict with high accuracy the firmness stage of avocado fruits; and b) these impact response parameters are more accurate, in a fruit-per-fruit classification, than storage duration in days, and some of them significantly more accurate than puncture firmness. Figure 1 is a representation of the explained result of this analysis. On this figure, variables which cluster at any one end of the principal (the horizontal) axis, possess a correlation near to 1 between themselves (DM and DU, and CD/CT/FM/FD/FT/FP); correlation is near to -1 between any pair of variables coming from both groups (between DM and the rest, and DU and the rest). All analyzed variables lie near the principal axis (axis 1), that therefore explains most of their variance.

3.2. Evolution of firmness

The encircled areas in Figure 1 represent the change of the values of all variables as ripening of the fruits advances. Distance between the encircled areas (representing the position of each point or fruit in the created multidimensional space) shows this relative change of ripeness of the fruits during the testing period, for both ripening and storage temperatures.
Table 3 a includes the results of the analysis of multiple range

test for differences between the means for avocadoes stored at 6ºC. It shows that, for all impact variables, and for puncture firmness measurements (FP), the evolution of the fruits is slow and not significant up until the 30th day, where a rapid change of the fruits initiates, and then advances to senescence. During this fast-changing period of time, only variable DU (impact duration) shows further significant differences between the means. This parameter is shown to be the most sensitive to ripeness changes. Very similar results are observed for the 20ºC ripened fruits. In this case, rapid change ocurred on the 6th day. These points are the limits for marketable quality of avocadoes cv. "Hass". Considering, as is usual, 20N of double-plate puncture firmness (FP) as the limit for consumption of these fruits, the final testing date included clearly over-ripe fruits. It is also observed that fruits were much more over-ripe on the 11th day at 20ºC than on the 60th day at 6ºC, both final dates of the tests.

Table 4 shows the parameters of the multiple linear regression equations estimating FP on all the impact variables. All correlation coefficients are significant and very high.

3.3. Mathematical models

Models were searched to find out which ones best describe the ripening evolution of avocado fruits. The exponential model named after Gompertz:

$$y=ae^{\left(-\frac{b}{c}e^{-cx}\right)}$$

was finally selected as the best fitting. TABLE 4 shows the parameters obtained for this equation, for both ripening and storage temperatures, and Figure 2 their representation. It has been shown that any of the non-destructive impact parameters follows also a Gompertz evolution. Physiological variables like respiration and ethylene production rate also evolve according to this model during the ripening period. Taking into account the different duration of both tests, it is assumed that an estimate of firmness can be made for intermediate storage temperatures. Further testing should confirm this assumption. For example, for an intermediate temperature of 13ºC the change would start at the 19th day of storage of the fruits.

Further development of the software attached to the impact measurement device allows for automatic calculation of classification criteria in any specified number of ripeness classes (2 to 10) at the first phase. Information from pre-classified fruits is fed into the computer. Once the quality indeces are calculated, classification of any number of similar fruits is performed. This procedure is described elsewhere (Jarén, Ruiz-Altisent and Perez, 1992).

4. Conclusions

Firmness of avocado fruits can be effectively and accurately measured by non-destructive impact. The ripeness evolution of fruits ripened at 20ºC and stored at 6ºC can be followed by one or various parameters of the impact response, and quality indeces

based on these parameters can be calculated to classify the fruits into ripeness classes, during the storage and shelf-life periods of time.
From the knowledge of this impact response it is possible to determine the initiation of rapid ripeness change, and therefore to program the marketing of avocado fruits, in terms of days of storage up to full ripening.
Mathematical models have been adjusted to firmness (i.e. ripeness) of these fruits, being the double-exponential Gompertz model the most appropriate to describe the process, for both tested temperatures. Different assumptions as to the progress of the ripening process of stored avocado fruits can be extracted and programmed using this model.
Software for the application of these results has been developed, to be used in an automatic fruit classification and sorting device, applicable for any impact-tested fruits.

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TABLE 1 - Selected impact parameters, included in the analysis, and values of their linear correlation with firmness {n=135 (6 °C) and n=75 (20 °C)}.

VARIABLES	UNITS	SYMBOLS	CORRELATIONS WITH FIRMNESS VALUES	
			6 °C	20 °C
Impact Duration	**ms**	**DU**	-0,896	-0,950
Fuerza/Tiempo Slope	kN/s	FT	0,942	0,876
Force/Deform. Slope	**N/mm**	**FD**	**0,943**	**0,885**
Maximun Force	**N**	**FM**	**0,947**	**0,940**
Maximum Deformation	**mm**	**DM**	**-0,933**	**-0,944**
Coefficient FT*FM	**kN^2/s**	**CT**	**0,950**	**0,871**
Coefficient FD*FM	**$(N^2/mm)*10^{-3}$**	**CD**	**0,946**	**0,871**
Máx. Penetration Force=Firmness	**N**	**FP**	**1,000**	**1,000**
Storage duration	**Days**	**Days**	**-0,910**	**-0,820**

TABLE 2. Correlations between the selected impact variables, plus two suplementary variables, and the principal axes in the principal component analysis results, for 6ºC storage and 20ºC ripening.

VARIABLES (Symbols)	FACTOR 1	FACTOR 2	FACTOR 1	FACTOR 2
	6ºC	6ºC	20ºC	20ºC
DU	-0.944	0.303	-0.938	0.316
FD	0.980	0.053	0.982	0.125
FT	0.977	0.026	0.978	0.141
DM	-0.967	0.935	-0.921	0.362
FM	0.979	0.087	0.983	0
CD	0.982	0.143	0.977	0.185
CT	0.984	0.120	0.976	0.192
(SUPLEMENTARY)				
DAYS	-0.886	-0.051	-0.858	0.110
FP	0.962	0.026	0.936	-0.233

TABLE 3 a - Firmness and impact parameters for avocado fruits cv."Hass" stored at + 6 °C (Average values of 15 observations)*

DAY	DU (ms)	FT (N/s)	FD (N/mm)	FM (N)	DM mm	CT (kN^2/s	CD $(N^2/mm)*10^{-3}$	FP (N)
0	2,753^{D}	66,719^{A}	93,031^{A}	58,663^{A}	0,852^{B}	3,929^{A}	5,480^{A}	76,453^{A}
11	2,733^{D}	64,487^{A}	88,827^{A}	57,669^{A}	0,839^{B}	3,327^{A}	5,132^{AB}	75,929^{A}
18	2,800^{D}	64,487^{A}	85,005^{A}	53,237^{A}	0,869^{B}	3,429^{A}	4,527A^{B}	74,294^{A}
25	2,907^{D}	61,485^{A}	82,603^{A}	52,083^{A}	0,899^{B}	3,198^{A}	4,309^{B}	72,856^{A}
32	2,947^{D}	60,733^{A}	76,349^{A}	54,037^{A}	0,921^{B}	3,285^{A}	4,055^{B}	67,493^{A}
39	3,100^{D}	57,667^{B}	77,989^{A}	49,954^{A}	0,908^{B}	3,035^{A}	4,055^{B}	47,656^{B}
46	4,180^{C}	28,385^{C}	36,201^{B}	32,715^{B}	1,277^{A}	0,930^{B}	1,193^{C}	9,810^{C}
53	5,687^{B}	19,943^{C}	26,007^{B}	28,103^{B}	1,345^{A}	0,566^{B}	0,739^{C}	5,559^{C}
60	6,233^{A}	19,917^{C}	24,865^{B}	28,426^{B}	1,349^{A}	0,567^{B}	0,708^{C}	4,055^{C}

TABLE 3 b - Firmness and impact parameters for avocado fruits cv. "Hass" stored at + 20 °C (Average values of 15 observations).

DAY	DU (ms)	FT (kN/s)	FD N/mm	FM (N)	DM mm	CT (kN^2/S)	CD $(N^2/mm)*10^{-3}$	FP (N)
0	2,753^{C}	66,719^{A}	93,031^{A}	58,663^{A}	0,852^{C}	3,929^{A}	5,480^{A}	76,453^{A}
5	2,787^{C}	67,344^{A}	89,400^{A}	58,240^{A}	0,845^{C}	3,935^{A}	5,223^{A}	75,735^{A}
7	2,900^{C}	52,474^{B}	70,563^{B}	49,009^{B}	0,901^{BC}	2,582^{B}	3,471^{B}	67,755^{A}
9	3,720^{B}	35,871^{C}	47,205^{C}	39,093^{C}	0,991^{AB}	1,407^{C}	1,852^{C}	40,027^{B}
11	4,920^{A}	26,723^{C}	33,139^{C}	29,271^{D}	1,272^{A}	0,793^{C}	0,982^{C}	3,036^{C}

*For each variable, average values with the same letter are not significantly different ($p<0,05$) according to DUNCAN's Multiple range test.

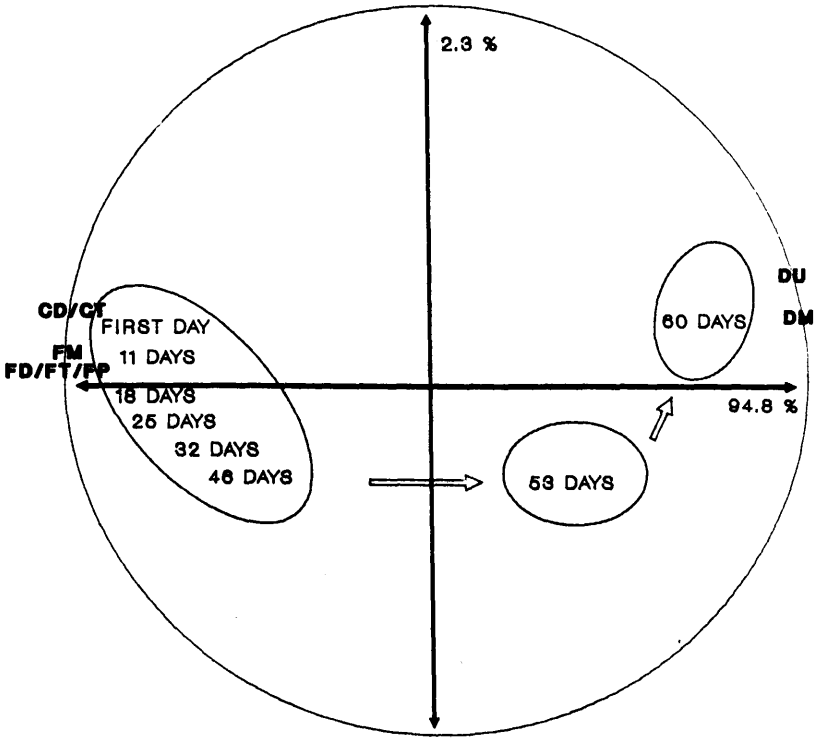
TABLE 4. Values of the parameters of the multiple linear regression equations which estimate FP (firmness) from the impact parameters. (Parameter symbols: see Table 1.- R = correlation coefficients).

Equation	Ind.term	DU	FD	FT	DK	FK	CD	CT	R
20ºC (n=75)	2.839	1.670	4.235	-4.792	-45.656	2.197	-72.730	79.326	0.974
6ºC (n=135)	- 1.394	0.544	0.472	0.083	-28.047	0.916	-4.546	5.653	0.964
20ºC and 6ºC (n=210)	8.396	-1.339	0.966	0.456	-48.779	1.755	-16.740	10.610	0.962

TABLE 5. Estimates of the values of the parameters in "Gompertz" equation for 20ºC and 6ºC storage temperatures. R = Correlation coefficient of the model with measured values.

Temp.	a	b	c	R
20ºC (n=75)	77.046	-0.0004	-0.811	0.990
6ºC (n=135)	75.524	-0.0001	-0.217	0.980

FIGURE 1a. MULTIPLE COMPONENTS ANALYSIS
Avocado "Hass" stored at 6ºC.



IMPACT RESPONSE

FIGURE 1 b. MULTIPLE COMPONENT ANALYSIS
Avocado "Hass" stored at 20ºC.

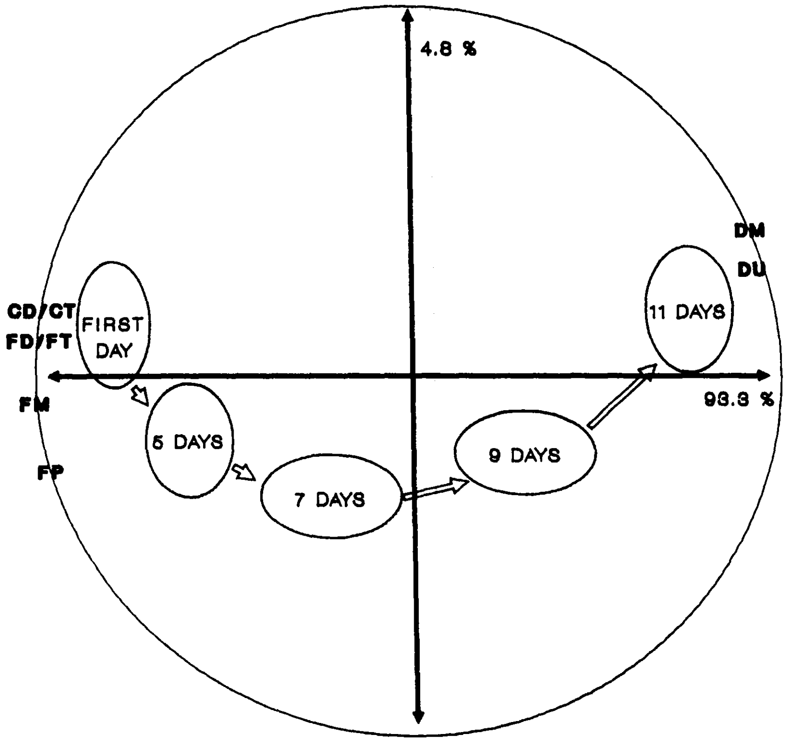


FIGURE 2 - FP (firmness) values observed and calculated (Gompertz model) for 20ºC and 6ºC.